

AMENDMENTS TO THE CLAIMS

The claims and their status are reflected below. Claims 55-77 are pending in this application, prior to any amendments below.

1. – 54. (cancelled)

55. (Previously presented) A method of measuring alignment accuracy between two or more patterned layers formed on a substrate comprising:

forming test areas as part of the patterned layers, wherein a first diffraction grating is built into a patterned layer A and a second diffraction grating is built into a patterned layer B, where layers A and B are desired to be aligned with respect to each other, zero or more layers of other materials separating layers A and B, the two gratings substantially overlapping when viewed from a direction that is perpendicular to the surfaces of A and B;

observing the overlaid diffraction gratings using an optical instrument capable of measuring reflectance as a function of wavelength or polarization of illumination and detection using the instrument, or capable of measuring ellipsometric parameters as a function of wavelength of the illumination and detection; and

determining the offset between the gratings from the measurements from the optical instrument using an optical model, wherein the optical model accounts for the diffraction of the electromagnetic waves by the gratings and [the interaction of the gratings with each other's diffracted field.

56. (Previously presented) The method of claim 55 wherein any layers between the grating in layer A and the grating in layer B are at least partially transparent at the wavelength range of the optical instrument.

57. (Previously presented) The method of claim 55 wherein at least one layer between the grating in layer A and the grating in layer B is opaque in the wavelength range of the optical instrument, and the presence of the grating in layer A causes a grating-shaped topography on the surface of the opaque layer.

58. (Previously presented) The method of claim 55 wherein the optical model represents the electromagnetic field in the gratings and in the layers between the gratings as a sum of more than one diffracted orders.

59. (Previously presented) The method of claim 55 wherein offset is determined by: calculating, according to a model of a wafer sample, the optical response of the sample with said two overlapping gratings, the model of the sample taking into account parameters of the sample including any of the overlay misalignment of layers A and B, and a profile parameter of the grating structures; and minimizing the difference between the calculated and measured optical responses

60. (Previously presented) The method of claim 59 wherein at least a portion of the calculated optical response is retrieved from a pre-computed database.

61. (Previously presented) The method of claim 55 wherein at least one of the two gratings contains more than one line per pitch, the widths of the at least two lines in each pitch (unit cell) being substantially different from each other.

62. (Previously presented) A method of measuring alignment accuracy between two or more patterned layers formed on a substrate comprising:

forming test areas as part of the patterned layers, wherein a first diffraction grating is built into a first patterned layer and a second diffraction grating is built into a second patterned layer, the two gratings substantially overlapping when viewed from a direction that is perpendicular to the surfaces of A and B, and at least one of the first or second gratings having a repeating pattern consisting of at least two structures of substantially different lateral dimensions;

measuring the optical characteristics of the overlaid diffraction gratings using an optical instrument with a spot size covering portions of the overlapping gratings; and

determining the offset between the gratings from the measured optical characteristics.

63. (Previously presented) A method of determining a degree of registration between an upper layer and a lower layer formed on a substrate, each of said layers including a periodic structure formed thereon and arranged to at least partially overlap, said method comprising the steps of:

illuminating the layers with a probe beam of radiation;
monitoring the zeroth order light diffracted from the layers;
generating a parameterized model representing the geometry and registration of parameters of the model; and
comparing the predicted optical response with the monitored zeroth order light to determine the registration of the structures.

64. (Previously presented) A method as recited in claim 63 wherein said generating step is at least partially carried out in advance for a number of different parameters and wherein the corresponding responses are stored in a database for later comparison with the monitored response.

65. (Previously presented) A method as recited in claim 63 wherein said probe beam is generated from a broadband source and said monitoring step is carried out as function of wavelength.

66. (Previously presented) An apparatus for determining overlay error between two or more patterned layers of a sample, comprising,
a metrology target comprising a first diffraction grating built into a patterned layer A and a second diffraction grating built into a patterned layer B, where layers A and B are part of the sample under test and layers A and B are desired to be aligned with respect to each other, the two gratings substantially overlapping when viewed from a direction that is perpendicular to the layers A and B;
an optical instrument that illuminates the metrology target and that measures properties of light that has interacted with the metrology target as a function of polarization of the illumination and detection; and
a processor which estimates the offset of the grating pair from the measured properties.

67. (Previously presented) The apparatus of claim 66 wherein at least one of the two gratings contains more than one line per pitch, the widths of the at least two lines in each pitch (unit cell) being substantially different from each other.

68. (Previously presented) The apparatus of claim 66 wherein at least one other layer of material separates layers A and B at the metrology target.

69. (Previously presented) The apparatus of claim 66 wherein the optical instrument measures properties of light that has interacted with the metrology target as a function of wavelength.

70. (Previously presented) The apparatus of claim 66 wherein the processor has been programmed to (i) calculate an optical response for a set of sample parameters, including overlay misalignment, (ii) compare the measured properties with the calculated optical response, and (iii) minimize the difference between the measured properties and the calculated optical response,

wherein the calculation of an optical response is according to an optical model of the sample that accounts for the diffraction of electromagnetic waves by the pair of gratings of the metrology target and the interaction of the gratings with each other's diffracted field.

71. (Previously presented) The apparatus of claim 70 wherein the processor has access to a pre-computed database from which at least a portion of the calculated optical response can be retrieved.

72. (Previously presented) An apparatus for determining the overlay error comprising,

a metrology target comprising a first diffraction grating built into a patterned layer A and a second diffraction grating is built into a patterned layer B, where layers A and B are desired to be aligned with respect to each other, the two gratings substantially overlapping when viewed from a direction that is perpendicular to the layers A and B;

an ellipsometer that illuminates the metrology target and that measures properties of light that has interacted with the metrology target; and

a processor which estimates the offset of the grating pair from the pair's measured optical characteristics.

73. (Previously presented) The apparatus of claim 72 wherein at least one of the two gratings contains more than one line per pitch, the widths of the at least two lines in each pitch (unit cell) being substantially different from each other.

74. (Previously presented) The apparatus of claim 72 wherein at least one other layer of material separates layers A and B at the metrology target.

75. (Previously presented) The apparatus of claim 72 wherein the ellipsometer measures properties of light that has interacted with the metrology target as a function of wavelength.

76. (Previously presented) The apparatus of claim 72 wherein the processor has been programmed to (i) calculate an optical response for a set of sample parameters, including overlay misalignment, (ii) compare the measured properties with the calculated optical response, and (iii) minimize the difference between the measured properties and the calculated optical response, wherein the calculation of an optical response is according to an optical model of the sample that accounts for the diffraction of electromagnetic waves by the pair of gratings of the metrology target and the interaction of the gratings with each other's diffracted field.

77. (Previously presented) The apparatus of claim 76 wherein the processor has access to a pre-computed database from which at least a portion of the calculated optical response can be retrieved.

78. (New) A method of obtaining overlay measurements for a semiconductor wafer, the method comprising:

forming a periodic grating on the wafer having:

a first set of gratings,

wherein the first set of gratings are formed on the wafer using a first mask, and

a second set of gratings,

wherein the second set of gratings are formed on the wafer using a second mask,

wherein the first and second sets of gratings are intended to be formed on the wafer with an intended asymmetrical alignment when the first mask and second mask are in alignment;

measuring a diffraction signal of the first and second sets of gratings after the first and second sets of gratings are formed on the wafer; and

determining a misalignment between the first and second sets of gratings formed on the wafer based on the measured diffraction signal.

79. (New) The method of claim 78, wherein the measured diffraction signal is a zero-order diffraction.

80. (New) The method of claim 79, wherein only the zero-order diffraction is measured.

81. (New) The method of claim 78, wherein the diffraction signal is measured using an optical metrology system.

82. (New) The method of claim 81, wherein the optical metrology system includes an ellipsometer.

83. (New) The method of claim 81, wherein the optical metrology system includes a reflectometer.

84. (New) The method of claim 78, wherein the diffraction signal is measured using an incident signal with a normal incidence angle.

85. (New) The method of claim 78, wherein the diffraction signal is measured using an incident signal with an oblique incidence angle.

86. (New) The method of claim 85, wherein the incident signal has an azimuthal angle of zero degrees.

87. (New) The method of claim 85, wherein measuring the diffraction signal includes:
measuring the amplitude of the diffraction signal.

88. (New) The method of claim 78 further comprising:

generating a set of diffraction signals for a range of possible misalignments between the first and second sets of gratings,

wherein each diffraction signal in the set corresponds to a different possible misalignment within the range of possible misalignments.

89. (New) The method of claim 88 further comprising:

generating a response curve of the correspondence between the different possible misalignments of the first and second sets of gratings and the set of diffraction signals.

90. (New) The method of claim 88 further comprising:

determining the intended asymmetric alignment between the first and second sets of gratings based on the generated set of diffraction signals and range of possible alignments.

91. (New) The method of claim 88, wherein the set of diffraction signals are

generated empirically.

92. (New) The method of claim 88, wherein the set of diffraction signals are

generated using modeling.

93. (New) The method of claim 88, wherein the determining the misalignment

between the first and second sets of gratings comprises:

comparing the measured diffraction signal to the generated set of diffraction signals; and

determining the possible misalignment that corresponds to the diffraction signal from the generated set of diffraction signals that matches the measured diffraction signal.

94. (New) The method of claim 78,

wherein the first and second sets of gratings include a plurality of ridges that repeat at a periodic interval, and

wherein the ridges of the first and second sets of gratings alternate.

95. (New) The method of claim 94,

wherein the ridges of the first and second sets of gratings include centerlines having a spacing between the centerlines of the ridges of the first and second sets of gratings, and

wherein the first and second sets of gratings are symmetrically aligned when the spacing between the centerlines is uniform and asymmetrically aligned when the spacing between the centerlines is non-uniform.

96. (New) The method of claim 95, wherein the intended asymmetric alignment includes an offset from symmetrical alignment of the first and second sets of gratings.

97. (New) The method of claim 78,
wherein the first and second sets of gratings include a plurality of ridges that repeat at a periodic interval, and
wherein the ridges of the second set of gratings are formed on the ridges of the first set of gratings.

98. (New) The method of claim 97,
wherein the ridges of the first and second sets of gratings include centerlines, and
wherein the first and second sets of gratings are symmetrically aligned when the centerlines of the ridges of the first and second sets of gratings are aligned and asymmetrically aligned when the centerlines are not aligned.

99. (New) The method of claim 98, wherein the intended asymmetric alignment includes an offset from symmetrical alignment of the first and second sets of gratings.

100. (New) The method of claim 78, wherein forming a periodic grating on the wafer comprises:

forming a periodic grating in a first metrology field on the wafer;
forming a periodic grating in a second metrology field on the wafer,
wherein the first and second metrology fields are separated by a distance on the wafer;
obtaining overlay measurements from the first and second metrology fields; and
computing an error based on the obtained overlay measurements.

101. (New) A method of obtaining overlay measurements for a semiconductor wafer using a periodic grating, the method comprising:

forming a first set of gratings of the periodic grating on the wafer;

forming a second set of gratings of the periodic grating on the wafer,

wherein the first and second sets of gratings are formed using separate masks, and

wherein the second set of gratings are intended to be formed on the wafer with an intended asymmetrical alignment from the first set of gratings when the separate masks are in alignment;

generating a set of diffraction signals for a range of possible misalignments between the first and second sets of gratings,

wherein each of the diffraction signal in the generated set of diffraction signals corresponds to a possible misalignment between the first and second sets of gratings;

measuring a diffraction signal of the first and second sets of gratings after the first and second sets of gratings are formed on the wafer,

wherein the diffraction signal is measured; and

determining a misalignment between the first and second sets of gratings based on the measured diffraction signal and the generated set of diffraction signals.

102. (New) The method of claim 101, wherein the determining the misalignment between the first and second sets of gratings comprises:

comparing the measured diffraction signal to the generated set of diffraction signals; and

determining the possible misalignment that corresponds to the diffraction signal from the generated set of diffraction signals that matches the measured diffraction signal.

103. (New) The method of claim 101, wherein the measured diffraction signal is a zero-order diffraction.

104. (New) The method of claim 101 further comprising:

generating a plurality of sets of diffraction signals at various wavelengths and/or polarizations.

105. (New) The method of claim 101,
wherein the first and second sets of gratings include a plurality of ridges that alternate with a spacing between the ridges,
wherein the first and second sets of gratings are symmetrically aligned when the spacing between the ridges of the first and second sets of gratings is uniform and asymmetrically aligned when the spacing is non-uniform.

106. (New) The method of claim 101,
wherein the first and second sets of gratings include a plurality of ridges with centerlines,
wherein the ridges of the second set of gratings are formed on the ridges of the first set of gratings, and
wherein the first and second sets of gratings are symmetrically aligned when the centerlines of the ridges of the first and second sets of gratings are aligned and asymmetrically aligned when the centerlines are not aligned.

107. (New) A method of obtaining overlay measurements for a semiconductor wafer using a periodic grating formed on the wafer, the method comprising:
obtaining the wafer, wherein the period grating on the wafer comprises:
a first set of grating that were formed on the wafer using a first mask,
a second set of gratings that were formed on the wafer using a second mask,
wherein the first and second sets of gratings were intended to be formed on the wafer with an asymmetric alignment when the first mask and second mask are in alignment;
generating a set of diffraction signals for a plurality of possible misalignments between the first and second sets of gratings;
measuring a diffraction signal of the first and second sets of gratings from the obtained wafer,
wherein the diffraction signal is measured, and
wherein the measured diffraction signal is a zero-order diffraction;
comparing the measured diffraction signal to the generated set of diffraction signals; and

determining an amount and direction of misalignment between the first and second sets of gratings on the obtained wafer based on the possible alignment that corresponds to the diffraction signal from the set of diffraction signals that matches the measured diffraction signal.

108. (New) The method of claim 107,
wherein the periodic grating on the wafer further comprises:
a first periodic grating oriented for obtaining overlay measurements in a first coordinate direction, and
a second periodic grating oriented for obtaining overlay measurements in a second coordinate direction; and
wherein measuring a diffraction signal further comprises:
measuring a first diffraction signal from the first periodic grating, and
measuring a second diffraction signal from the second periodic grating without rotating the wafer.

109. (New) The method of claim 108, wherein the measured diffraction signals and the generated diffraction signals have amplitude ratios, and wherein the amplitude ratios of the measured diffraction signals are compared with the amplitude ratios of the generated diffraction signals.

110. (New) The method of claim 108, wherein the diffraction signals are measured using an oblique and conical incident signal.

111. (New) The method of claim 107, wherein the diffraction signal is measured using a normal incidence angle.

112. (New) The method of claim 107, wherein the diffraction signal is measured using an oblique incidence angle with an azimuthal angle.

113. (New) The method of claim 107, wherein the diffraction signal is measured using an oblique incidence angle with an azimuthal angle of zero degrees.

114. (New) The method of claim 107,
wherein the first and second sets of gratings include a plurality of ridges that alternate with a spacing between the ridges,
wherein the first and second sets of gratings are symmetrically aligned when the spacing between the ridges of the first and second sets of gratings is uniform and asymmetrically aligned when the spacing is non-uniform.

115. (New) The method of claim 107,
wherein the first and second sets of gratings include a plurality of ridges with centerlines,
wherein the ridges of the second set of gratings are formed on the ridges of the first set of gratings, and
wherein the first and second sets of gratings are symmetrically aligned when the centerlines of the ridges of the first and second sets of gratings are aligned and asymmetrically aligned when the centerlines are not aligned.

116. (New) A system to obtain overlay measurements of a semiconductor wafer, the system comprising:
a periodic grating formed on the wafer comprising:
a first set of gratings formed using a first mask,
a second set of gratings formed using a second mask, and
wherein the first and second sets of gratings are intended to be formed with an asymmetric alignment when the first mask and second mask are in alignment; and
an optical metrology system comprising:
a detector configured to measure a diffraction signal from the first and second sets of gratings, and
a signal processing unit configured to determine a misalignment between the first and second sets of gratings based on the measured diffraction signal.

117. (New) The system of claim 116, wherein the signal processing unit is configured to compare the measured diffraction signal to a set of diffraction signals generated for a plurality of possible alignments between the first and second sets of gratings.

118. (New) The system of claim 116, wherein the periodic grating further comprises:
a first periodic grating oriented in a first coordinate direction; and
a second periodic grating oriented in a second coordinate direction,
wherein overlay measurements can be obtained in the first and second coordinate directions using the first and second periodic gratings without rotating the wafer.

119. (New) The system of claim 118, wherein the optical metrology system comprises:

a source configured to produce an oblique and conical incident signal.

120. (New) The system of claim 116, wherein the optical metrology system comprises:

a source configured to produce a normal incident signal.

121. (New) The system of claim 116, wherein the optical metrology system comprises:

a source configured to produce an incident signal having an oblique incidence angle and an azimuthal angle of zero degrees.

122. (New) The system of claim 116, wherein the periodic grating comprises:
a first portion with the first and second sets of gratings having a first alignment; and
a second portion with the first and second sets of gratings having a second alignment.

123. (New) The system of claim 122,
wherein the detector is configured to measure a first diffraction signal from the first portion of the period grating and a second diffraction signal from the second portion of the periodic grating, and

wherein the signal processor is configured to determine the amount and direction of misalignment between the first and second sets of gratings based on the measured first and second diffraction signals.

124. (New) The system of claim 123, wherein the signal processor is configured to determine the alignment of the first and second sets of gratings by comparing the difference between the measured first and second diffraction signals to a set of difference signals generated for a plurality of possible misalignments between the first and second sets of gratings.

125. (New) The system of claim 123, wherein the periodic grating further comprises:
a third portion having only the first set of gratings; and
a fourth portion having the second set of gratings.

126. (New) The system of claim 125, wherein the optical metrology system comprises:

a library of simulated-diffraction signals having a set of theoretical geometry of the first and second sets of gratings;

wherein the detector is configured to measure a diffraction signal from the third portion and a diffraction signal from the fourth portion; and

wherein the signal processing unit is configured to compare the measured diffraction signal to the simulated-diffraction signals to determine the geometry of the first and second sets of gratings.

127. (New) The system of claim 116, wherein the first and second sets of gratings include a plurality of ridges that alternate with a spacing between the ridges; and wherein the first and second sets of gratings are symmetrically aligned when the spacing between the ridges of the first and second sets of gratings is uniform and asymmetrically aligned when the spacing is non-uniform.

128. (New) The system of claim 116, wherein the first and second sets of gratings include a plurality of ridges with centerlines; wherein the ridges of the second set of gratings are

formed on the ridges of the first set of gratings; and wherein the first and second sets of gratings are symmetrically aligned when the centerlines of the ridges of the first and second sets of gratings are aligned and asymmetrically aligned when the centerlines are not aligned.

129. (New) A method to obtain overlay measurements for a semiconductor wafer, comprising:

measuring a diffraction signal of a first set of grating and a second set of gratings of a periodic grating formed on the wafer, wherein

the first set of gratings were formed using a first mask,

the second set of gratings were formed using a second mask, and

wherein the first and second sets of gratings were intended to be formed on the wafer with an asymmetric alignment when the first mask and second mask are in alignment;

generating a set of diffraction signals for a plurality of possible misalignments between the first and second sets of gratings;

determining a misalignment of the first and second sets of gratings formed on the wafer based on the measured diffraction signal and the generated set of diffraction signals; and

130. (New) The method of claim 129, further comprising:

obtaining the geometry of the first set of gratings; and

obtaining the geometry of the second set of gratings,

wherein the generated set of diffraction signals is generated based on the obtained geometry of the first and second sets of gratings.

131. (New) The method of claim 130, further comprising:

measuring diffraction signals of the first set of gratings;

measuring diffraction signals of the second set of gratings; and

comparing the measured diffraction signals to a library of simulated-diffraction signals having a set of theoretical geometry of the first and second sets of gratings.

132. (New) The method of claim 131, wherein the diffraction signals of the first set of gratings are measured from a third portion of the grating having only the first set of gratings, and

the diffraction signals of the second set of gratings are measured from a fourth portion of the grating having the second set of gratings.

133. (New) The method of claim 129, further comprising:
- measuring a first diffraction signal from a first periodic grating;
 - determining the amount and direction of misalignment between the first and second sets of gratings in a first coordinate direction using the first measured diffraction signal;
 - measuring a second diffraction signal from a second periodic grating without rotating the wafer; and
 - determining the amount and direction of misalignment between the first and second sets of gratings in a second coordinate direction using the second measured diffraction signal.